Port-Hamiltonian systems

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Port-Hamiltonian systems: an approach to modelling and control of complex physical systems

Abstract

Prevailing trend in the modeling and simulation of complex (lumped-parameter) physical systems is modular modeling, where the complex physical system is represented as the network interconnection of ideal components. This has many advantages in terms of flexibility, re-usability of model parts, and support for automated modeling. The viewpoint of network modeling necessarily leads to the consideration of *open dynamical systems*, that is, dynamical systems with external variables, which can be interconnected to other open systems. This viewpoint is fundamental to systems and control theory, where the *analysis* and *design* of complex systems is based on the properties of the sub-systems and the way they are interconnected to each other, and where the behavior of the complex system is sought to be influenced by the addition of additional feedback loops and control components.

On the other hand, the *equations of motion* obtained from direct network modeling are often complicated and without apparent structure, and will easily contain algebraic constraints arising from the interconnection of the sub-systems. As such, they may not be very suited to analysis and control. During the last fiteen years it has been shown how a particular type of network modeling, namely *port-based modeling*, where the sub-systems are interacting with each other through power exchange represented by pairs of conjugated variables, immediately leads to generalized Hamiltonian equations of motion. In fact, the interconnection structure of the complex system, together with power-preserving elements like transformers and workless constraints, defines a geometric object, which is called a *Dirac structure*. The equations of motion are Hamiltonian with respect to this Dirac structure and the Hamiltonian defined by the total energy of the system, together with the energy-dissipation structure. The resulting class of geometrically defined systems has been called *port-Hamiltonian systems*. Recently, this framework has been extended to distributed-parameter systems, by considering infinite-dimensional Dirac structures based on Stokes' theorem. Typical infinite-dimensional components include the transmission line, Maxwell's equations on a bounded domain, beam models, as well as ideal fluid models.

The framework of port-Hamiltonian systems offers many possibilities for the analysis, simulation and control of complex nonlinear and infinite-dimensional physical systems. Indeed, from the underlying Hamiltonian structure structural properties like energy conservation and other balance laws are easily identified. Also the algebraic constraints are seen to have a special structure, which fact may be used for their elimination so as to obtain a port-Hamiltonian system *without* constraints. All these properties may be fruitfully used, often leading to a physically interpretable and robust control design. One approach is to interconnect the plant port-Hamiltonian system to a controller port-Hamiltonian system, and thus to generate Lyapunov functions based on the (shaped) Hamiltonian and balance laws of the closed-loop system. A related approach is to add feedback so as to transform the port-Hamiltonian system into a new port-Hamiltonian system with desired properties ('virtual re-design').

This mini-symposium will collect some recent advances in the area of port-Hamiltonian systems. It will start with a general introduction to the theory of port-Hamiltonian systems, emphasizing the main concepts and treating some typical examples. This will be followed up by a series of 20 minutes presentations.

Key references

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3. A.J. van der Schaft, B.M. Maschke, ' "Hamiltonian formulation of distributed-parameter systems with boundary energy flow", *Journal of Geometry and Physics, vol. 42*, pp.166-194, 2002.